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Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

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Dear Mr. Gillis:

Submitted for your consideration is a report on:

Relative Strength and Shrinkage Tests
of Concrete Using Various Types of
Cement, Cement Factors, and
Cement-Calcium Chloride Combinations

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Very truly yours

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Relative Strength and Shrinkage Tests of Concrete, Using Various Types of Cement, Cement Factors, and Cement-Calcium Chloride Combinations

Synopsis

From time to time on various projects, special traffic requirements make it necessary to open portions of concrete pavements or structures to traffic within a very short time after the concrete is placed. This generally calls for special measures to provide the needed early strength.

Methods that have been proposed are:

1. Increased cement factor
2. Use of high-early strength (Type III) cement
3. Use of an accelerator (usually calcium chloride)
4. Some combination of the above.

In order to provide more complete and accurate information on the relative effects of the various combinations on (1) early strength and (2) drying shrinkage, mixes employing ten different combinations were tested for strength at various ages from 6 hours to 28 days, as well as

for drying shrinkage.

The results are shown in the Appendix and discussed briefly in the Summary of Test Results. Figures 1, 2 and 3 of the Appendix provide a graphical summary of essential data. It should be remembered that actual test values apply only to the concrete used in these tests. The relative values would generally apply to other concrete as well.

End of Synopsis

Summary of Test Results

The following combinations were tested:

Cement Type	Sacks/Cu.Yd.	Admixture
II	5	None
II	6	None
II	7	None
II	8	None
II	5	2% $CaCl_2$
II	7	2% $CaCl_2$
III	5	None
III	6	None
III	7	None
III	6	2% $CaCl_2$

Test results are listed and compared in the tables and graphs in the Appendix to this report. The tables and graphs are in general, self-explanatory.

Some significant results which have been noted and should be considered in selecting a combination for high early strength are as follows:

1. The highest 6-hour and 3-day compressive strengths were obtained with the 6-sack, Type III cement mix, using 2% calcium chloride; however, this combination also produced the largest drying shrinkage.

$CaCl_2$ in excess of 2% by weight has little effect on early strength but affects other properties adversely.

2. If, as a basis for comparison, it is assumed that a strength approximately equal to that obtained in 14 days with a 5-sack, Type II mix would usually be sufficient to meet most high early strength requirements, the test results indicate that the following combinations would meet or exceed this criterion in three days.

	Order of Shrinkage ("1" is least shrinkage)	Cost of Cement + $CaCl_2$ when Used*	Added Cost over 5-sack Type II
8-sack, Type II	1	$ 9.60	$ 3.60
6-sack, Type III	5	7.95	1.95
7-sack, Type III	4	9.30	3.30
7-sack, Type II, w/2% $CaCl_2$	6	9.18	3.18
6-sack, Type III, w/2% $CaCl_2$	7	8.68	2.61
5-sack, Type II	3	6.00	----

*Type II at $4.80 per bbl.
Type III at $5.30 per bbl.
$CaCl_2$ at $0.06 per lb.

Of the 5 combinations listed above, the 8-sack, Type II mix was the only one that did not show drying shrinkage greater than that recorded for the 5-sack, Type II mix. Of

all combinations, the 6, 7, and 8-sack, Type II, plain mixes all had drying shrinkage less than the 5-sack, Type II mix. The sand content of all mixes containing more than 5 sacks per cubic yard was reduced as the cement factor was increased. The reduction was about 3% to 4% for each additional sack of cement. (See Table 2.) Had the sand content not been reduced, a sticky mix would result and the shrinkage would have been greater as the cement factor was increased.

The selection of a mix for a particular case will depend on such variable factors as:

1. The minimum strength considered necessary at a given age, in the specific instance.
2. The urgency of the need for early strength; i.e., whether it is considered desirable in the specific case to try for the maximum attainable early strength without regard for drying shrinkage.

The choice of method for obtaining high early strength should be governed by what is adequate and what is practical to attain. The use of calcium chloride greatly increased drying shrinkage and its use should be avoided if cracking is a problem. Some of the other cement combinations exhibited high drying shrinkage and the choice should be the one giving the desired strength with the lowest shrinkage.

The values for strength shown are for the particular cements and aggregates used and may not be duplicated on field jobs using other materials. The relative strengths are the significant values.

Materials, Specimens, and Test Procedures

The materials used were as follows:

Aggregates:

American River, Fair Oaks (all batches)

Cements:

Calaveras, Type II and Type III

Admixture:

Commercial grade calcium chloride, 2% by weight of cement (where used).

As stated in the Summary of Test Results, ten different combinations were tested. Three rounds were made on different days for each combination. This was done by making 5 batches (combinations picked at random) on each

of 6 days. The wet concrete was tested for slump, air content, and unit weight.

Data for W/C ratios, cement factor, percent sand, relative shrinkage and relative strength are included in Table 2. Note that the sand percentage was reduced as the cement factor was increased.

Four cylinders (for compressive strength) and three 3x3x11-1/4 inch shrinkage specimens were made from each batch. The cylinders were cured in the fog room and one each broken at 6 hours, 3 days, 14 days, and 28 days.

The shrinkage specimens were cured in the fog room for 7 days, measured, then dried at 50% relative humidity for 14 days and measured again in accordance with Test Method No. Calif. 530-A.

Test data in tabular form and graphs comparing test results are in the Appendix to this report.

TABLE 1

Compressive Strength Data

	Strength, psi				% of 5-sack, Type II			
	Days				Days			
	6 Hr. (1/4)	3	14	28	6 Hr. (1/4)	3	14	28
5-sack, Type II	30	900	2160	2960	100	100	100	100
6-sack, Type II	60	1490	3230	4115	200	165	150	139
7-sack, Type II	80	1960	3990	4900	266	218	185	165
8-sack, Type II	100	2420	4590	5305	333	269	212	179
5-sack, Type II, $CaCl_2$	130	1490	2630	3150	432	165	122	106
5-sack, Type III	150	1620	3180	3680	500	180	147	124
6-sack, Type III	220	2390	3580	4430	730	265	166	150
7-sack, Type III	560	2820	4210	5020	1870	313	195	170
7-sack, Type II, $CaCl_2$	580	3260	4800	5660	1930	361	222	191
6-sack, Type III, $CaCl_2$	1100	3460	4790	5275	3700	384	222	178

3-Day Strengths vs. 14-day, 5-sack, Type II

	5 - II 14 day	2160	100%
	6 - II	1490	69
	5 - II, $CaCl_2$	1490	69
	5-- III	1620	75
	7 - II	1960	91
*	6 - III	2390	111
*	8 - II	2420	112
*	7 - III	2820	131
*	7 - II, $CaCl_2$	3260	151
*	6 - III, $CaCl_2$	3460	160

*These combinations equal or exceed 5-sack, Type II, 14-day strength at 3 days.

TABLE 2

Mix Data and Numerical Strength and Shrinkage Ratings
(1" Max. concrete - 3-1/2" slump)

	5-II	6-II	7-II	8-II	5-IIcc*	5-III	6-III	7-III	7-IIcc*	6-IIIcc*
Cement, Sks./CY	5	6	7	8	5	5	6	7	7	6
Water-cement Ratio, Lbs./Sk.	63.8	52.6	45.0	39.1	61.6	65.0	55.8	49.3	43.6	52.8
% Sand	50	46	43	40	50	50	46	43	43	46
Shrinkage Rating **	3	2	2	1	4	6	5	4	6	7
Strength at:										
6 hours***	1	2	3	4	5	6	7	8	9	10
72 hours	1	2	4	6	2	3	5	7	8	9
14 days	1	4	6	8	2	3	5	7	10	9

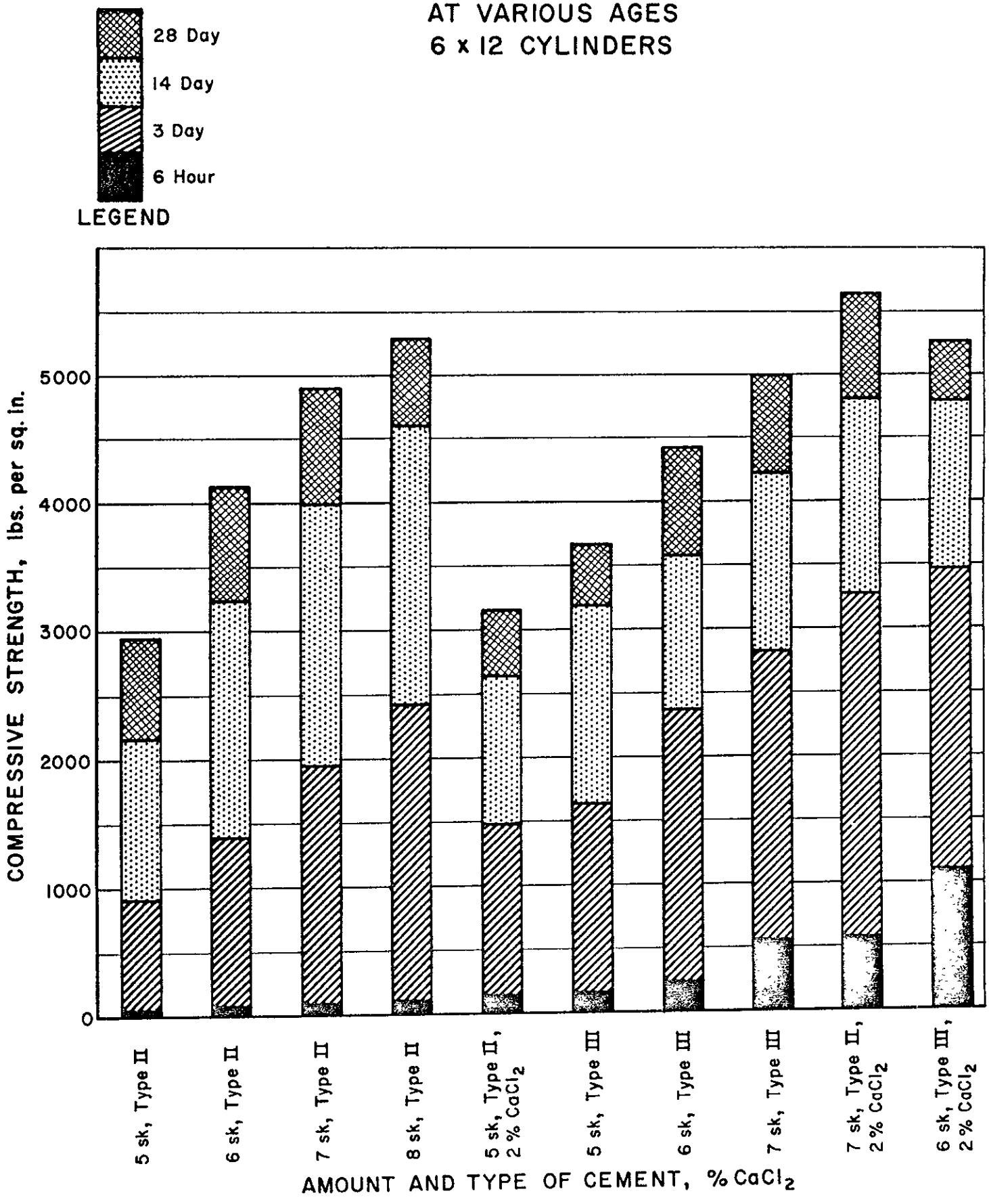
* cc is calcium chloride (2% by weight of cement)
** Combination with least shrinkage is No. 1, etc.
*** No. 1 has lowest strength, etc.

TABLE 3

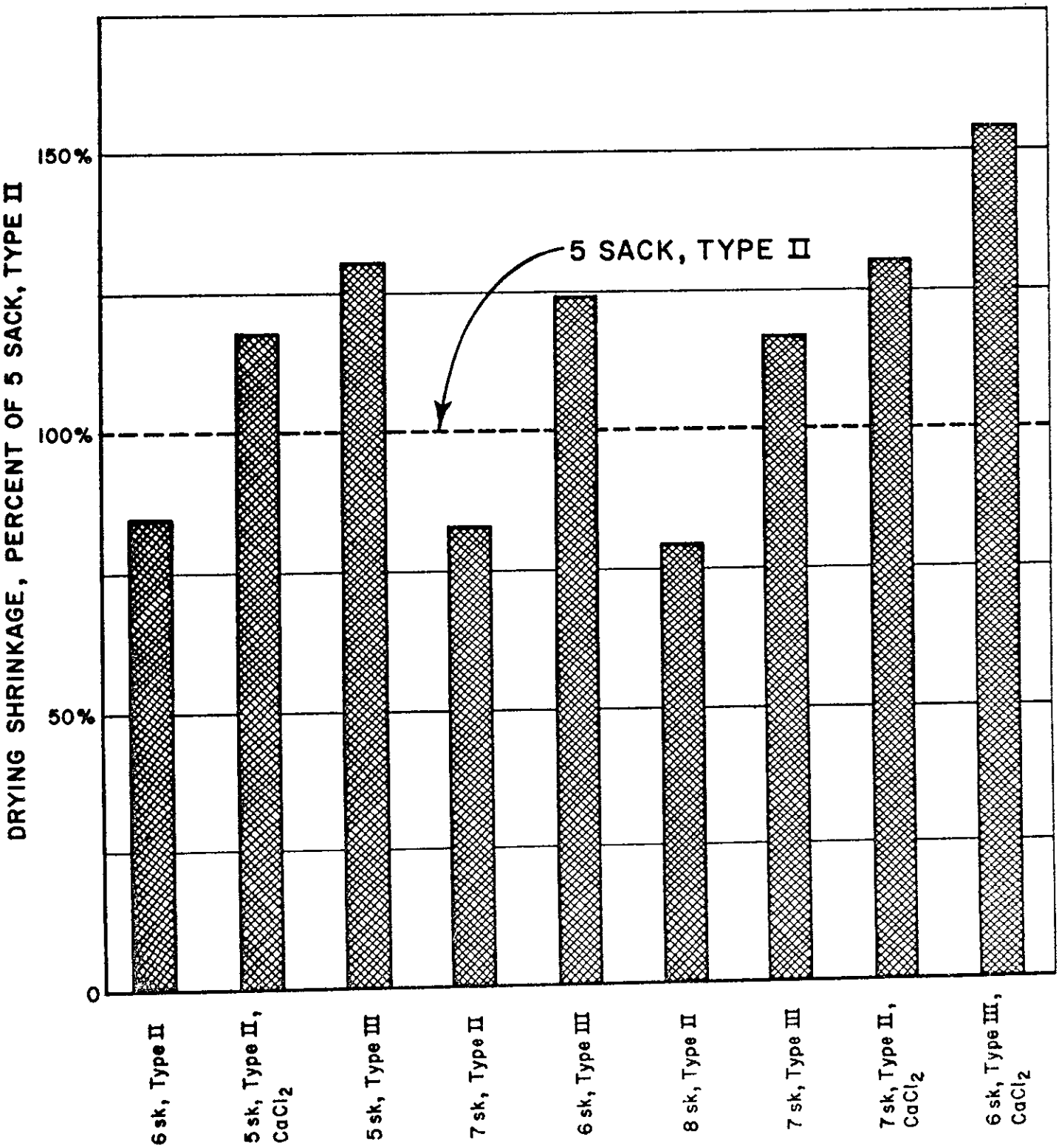
14-day Strength and Drying Shrinkage Data

	Strength, psi 14-days	Strength, % of 5-sack, Type II 14-days
5-sack, Type II	2160	100
5-II-$CaCl_2$	2630	122
5-III	3180	147
6-II	3230	150
6-III	3580	166
7-II	3990	185
7-III	4210	195
8-II	4590	212
6-III-$CaCl_2$	4790	222
7-II-$CaCl_2$	4800	222
	14-day Drying Shrinkage, %	**% of 5-sack Type II**
8-II	.0281	78
7-II	.0298	83
6-II	.0301	84
5-II	.0359	100
7-III	.0417	116
5-II-$CaCl_2$	.0422	118
6-III	.0446	124
5-III	.0466	130
7-II-$CaCl_2$	.0466	130
6-III-$CaCl_2$	.0551	154

COMPARISON OF COMPRESSIVE STRENGTHS AT VARIOUS AGES 6 x 12 CYLINDERS



14 DAY DRYING SHRINKAGE OF 3x3x11 1/4 INCH SPECIMENS PERCENTAGE OF 5 SACK, TYPE II



3 DAY COMPRESSIVE STRENGTHS AS A PERCENTAGE OF 5 SACK, TYPE II, AT 14 DAYS